2nd Pan Pacific Basin Workshop on Microgravity Sciences, 2001
FP-1097

THE LOW TEMPERATURE MICROGRAVITY PHYSICS FACILITY (LTMPF)

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ABSTRACT

The Jet Propulsion Laboratory is building the Low Temperature Microgravity Physics Facility (LTMPF) in partnership with Ball Aerospace Technologies Corporation and Design_Net Engineering. The LTMPF is a self contained, reusable, cryogenic facility that will be attached to the Japanese Experiment Module (KIBO) Exposed Facility of the International Space Station. The LTMPF is a state-of-the-art facility for long duration science investigations whose objectives can only be achieved in microgravity and at low temperature. Each flight will have an approximate cryogen lifetime of almost five months. Two distinct primary experiments will be accommodated during each mission. Secondary experiments are also planned during each mission utilizing the hardware built for the primary experiments. Currently four primary experiments have been selected as candidates for flight on the first two missions of the LTMPF. These primary experiments include fundamental physics research in the areas of condensed matter and gravitational physics. Two secondary experiments also have been recently selected for flight definition and are expected to fly as part of the first LTMPF mission. We will describe the LTMPF, its objectives, its science requirements, and provide a brief description of the science investigations. The current status of the project and the facility design including results on the performance of flight-like subsystems will also be presented.

INTRODUCTION AND HISTORY

The Jet Propulsion Laboratory (JPL) has a long history of providing support to low temperature experiments in space. JPL was involved in the development and flight of the first known liquid helium cooled cryogenic satellite, the Infrared Astronomical Satellite (IRAS). Also, JPL developed the Low Temperature Platform Facility (LTPF)[1] to provide a platform for short duration (less than 2 weeks), Space Shuttle based experiments that needed temperatures near 2K in a microgravity environment. The LTPF has flown on the Space Shuttle three times: in 1985 as the Superfluid Helium Experiment (SFHE), in 1992 as part of the first United States Microgravity Payload (USMP) with the Lambda Point Experiment (LPE)[2] installed, and in 1997 as part of USMP-4 with the Confined Helium Experiment (CHeX)[3] installed. The capabilities of the LTPF were increased between each mission, and all three of these experiments were highly successful. Unfortunately, by 1997 the construction of the International Space Station (ISS) brought about the end of regularly scheduled Space Shuttle flights dedicated to microgravity science payloads. Currently there are no plans for flying the LTPF again.

While the construction of the ISS has caused the loss of Shuttle opportunities for performing science, a new opportunity for long duration microgravity research has been created. To continue progress in low temperature microgravity research, and to take advantage of the opportunity provided by the ISS, a new low temperature platform is being developed by JPL.

OBJECTIVES

The objective of the LTMPF is to expand the capabilities provided previously by the LTPF to the Shuttle based experiments. The LTMPF is being designed to provide more frequent access to space than the 5+ year separation realized by the Space Shuttle experiments. The LTMPF will provide a significantly longer duration of low temperatures beyond the approximately two weeks available on the Shuttle. This longer duration will make possible experiments that need months in a microgravity environment to achieve their scientific goals. Also, unlike the LTPF, the LTMPF will provide support for two distinct experiments during each flight.

The LTMPF will be a self contained, reusable cryogenic facility that will accommodate a series of experiment pairs to be conducted on the ISS, attached at the Japanese Experiment Module Exposed Facility (JEM-EF). The LTMPF will be transported to and from the ISS on the Space Shuttle. The LTMPF will include a variety of high resolution sensors specific to the experiments including an improved version of the Superconducting Quantum Interference Devices (SQUIDs) flown on the previous Shuttle experiments. In addition, the LTMPF will accommodate additional sensors including high resolution capacitance sensors and higher resolution resistance bridges than previously flown. By increasing the type of sensors accommodated in the facility, the facility will be able to support a more diverse set of science investigations than was possible with the LTPF.

FACILITY CONCEPT

The LTMPF will provide the platform that interfaces both mechanically and electrically (including telemetry and command) with both the launch carrier and the ISS. The investigators will plug their individual experiments in to this platform. Much of the LTMPF concept is based on the experience with the previous, Shuttle based low temperature microgravity experiments. The LTMPF will consist of a cryogenic dewar, electronics, a mechanical support structure, and the interfaces necessary for attaching to the ISS and the launch vehicle (see Figure 1). The facility must fit within the envelope of a standard JEM-EF payload, 1.85m X 1.0m X 0.8m. Also, the total facility weight is limited to less than 600kg by the constraints of the launch carriers.

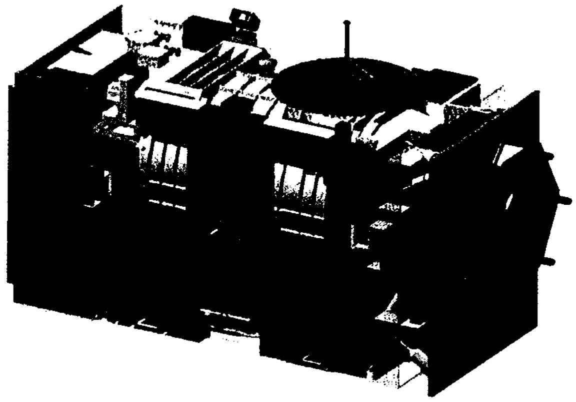

Figure 1: Schematic representation of the LTMPF showing the interfaces to the launch carrier (the FRAM on the side), the ISS manipulating arms (the Grapple fixture on the top), and the JEM-EF (the PIU on the end).

The central feature of the facility is the almost 200 liter superfluid helium dewar. The LTMPF dewar will be able to maintain a base temperature of approximately 1.6K for a period of about four and a half months. The dewar will house two separate scientific instruments consisting of both the experiment specific sensor package developed by the investigators and a cryo insert provided as a standard interface to the dewar by JPL.

To drive the scientific instruments located inside the dewar, the facility includes several electronics boxes outside the dewar dedicated to each experiment. The electronics being developed by Design_Net Engineering and the investigators include SQUID readouts and controls for making precision temperature and pressure measurements, high resolution capacitance bridges, and high precision heater power supplies. The LTMPF is also designing a generic resistance bridge and heater control for general temperature readout and control for use by both instruments and the facility.

The design of the facility, including the electronics is modular to meet the needs of both current and future experiments. The design allows for the incorporation of electronics developed by the investigators to increase the flexibility of the facility. The current electronics concept includes a separate single board computer for each experiment, with an additional computer controlling both the facility electronics and the interface between the LTMPF and the ISS (command and telemetry). All of the computers will have the capability of storing some of the data during on-orbit operations to cover Loss of Signal (LOS) events during each orbit.

Most of the current and projected experiments are sensitive to random vibrations, charged particles, and stray magnetic fields. The vibration and charged particle radiation environments will be monitored and real-time data on both will be included in the data telemetry. Several layers of magnetic shielding are incorporated around the cryogenic portion of the instrument to insulate the experiments from the on orbit variations in the magnetic field environment.

OPERATIONAL CONCEPT

Once all portions of the facility (electronics, dewar, and enclosure) and the two flight instruments are built and have passed preliminary subsystem testing by their developers, all the hardware will be shipped to JPL for integration and system testing. JPL will perform all the necessary flight qualification and functional testing along with any necessary system safety verifications. After passing all preflight testing, the LTMPF will be shipped to the launch site where JPL will provide additional support for carrier integration and launch operations. The launch of the first mission of the LTMPF is currently planned for late 2005. The LTMPF is being designed to launch and return using the Space Shuttle.

After the facility has been attached to the ISS at the JEM-EF, the two primary experiments and their guest investigations will take data until the helium supply in the dewar is exhausted, after approximately four and a half months. While attached to the JEM-EF, the experiments will run semi-autonomously through a telescience link to the Investigators' institution. The LTMPF will remain attached to the JEM-EF taking data on the vibration and charged particle environment after the helium supply is depleted until the LTMPF is returned, up to one year after launch. Once the facility is returned, the experiment specific hardware will be removed, and the hardware for the next mission's experiments will be integrated and tested. The second mission's launch is expected to be up to 30 months after the launch of the initial mission due to funding constraints. Later missions are expected to follow with only 22 months separating launches.

SELECTED EXPERIMENTS

There are currently six experiments selected to fly on the LTMPF, two primary experiments per mission, and two guest investigations selected for the first mission. The investigations were selected initially through the NASA Research Announcement (NRA) process. The NRA process chose three candidate experiments to compete for the two primary slots available on each mission. These initial three experiments were reduced to the two mission experiments through the standard flight experiment review process. The experiments for the first mission were selected at the successful conclusion of their Requirements Definition Reviews, while the experiments for the second mission were chosen after their Science Concept Review. The guest investigations for the first mission were selected from an NRA occurring after the two primary experiments had been chosen.

The two primary experiments that will fly on the first mission are Critical Dynamics in Microgravity (DYNAMX)[4] and the Microgravity Scaling Theory Experiment (MISTE)[5]. The two experiments selected for the second mission are Boundary Effects on the Superfluid Transition (BEST)[6] and Superconducting Microwave Oscillator (SUMO)[7]. As mentioned above, guest investigations were recently chosen to add to the scientific return of the first mission. One guest investigation has been selected to fly with each of the primary experiments.

The experiment CQ[8] will use the hardware being developed by DYNAMX, and COEX will make use of the hardware of the MISTE experiment.

All of these experiments except for SUMO are condensed matter experiments performed on samples of liquid helium (^{3}He or ^{4}He). SUMO represents a class of experiments exploring gravitational and relativistic physics in a low temperature microgravity environment. All of the experiments make use of the high precision, SQUID based thermometry which was first developed for LPE. These new experiments have continued this sensor development and have made noticeable improvements on the inherited technology. Each experiment has also developed their own unique high resolution sensors for pressure, density, or frequency, creating technology that has not previously flown.

The experiments selected for the first mission, DYNAMX and MISTE, received their Authority to Proceed (ATP) to Flight during the previous year after their successful Requirements Definition Reviews (RDR) in December of 1999. The guest investigations for the first mission will hold a combined SCR/RDR in March of 2002. After passing these reviews, the guest investigations will receive their Authority to Proceed to Flight, and they will join the development process with the primary experiments. The experiments for the second mission are expected to hold their RDRs in late 2004, after which they will also receive their ATP for flight.

LTMPF CURRENT DEVELOPMENT STATUS

Substantial design definition work has been performed over the past year on the LTMPF. The two experiments both passed a Preliminary Design Review (PDR) in November 2000. The cryogenic insert that interfaces between the dewar and the experiments passed a Critical Design Review, held concurrently in November. A system Preliminary Design Review was held in December of 2000. Because of the projected cost to compete, NASA did not let the full LTMPF system proceed directly to critical design. The LTMPF project has since successfully restructured by splitting the Facility hardware between two vendors, Ball Aerospace and Technologies Corporation for the dewar and the enclosure, and Design_Net Engineering for the electronics. Because of this restructuring, NASA has granted the LTMPF approval to move forward to a delta-PDR in September 2001.

Overall, substantial progress has been made on all of the subsystems for the LTMPF. Prototypes of several critical pieces of hardware have been developed and successfully performance tested. For example, each of the primary experiments on the first mission have built prototype instrument sensor packages that are being used to take ground science data. Several independent designs for resistance thermometer readout electronics were successfully performance tested. Other hardware was successfully tested at launch vibration levels. The hardware designs tested for launch survivability included delicate portions of the investigators' sensor packages and the cryogenic insert being developed at JPL to support the investigators' sensor package in LTMPF's helium dewar. The flight build of the cryogenic insert will being this summer. Also, the preliminary design of the dewar received approval to move to critical design work. Long lead procurement items for the dewar will be procured also this summer.

ACKNOWLEDGEMENTS

This work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract to the National Aeronautics and Space Administration. The work was funded by NASA's Office of Biological and Physical Research, Physical Sciences Division.

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2nd Pan-Pacific Basin Workshop on Microgravity Sciences

May 2, 2001

Low Temperature Microgravity Physics Facility

Low Temperature Research on the Space Shuttle

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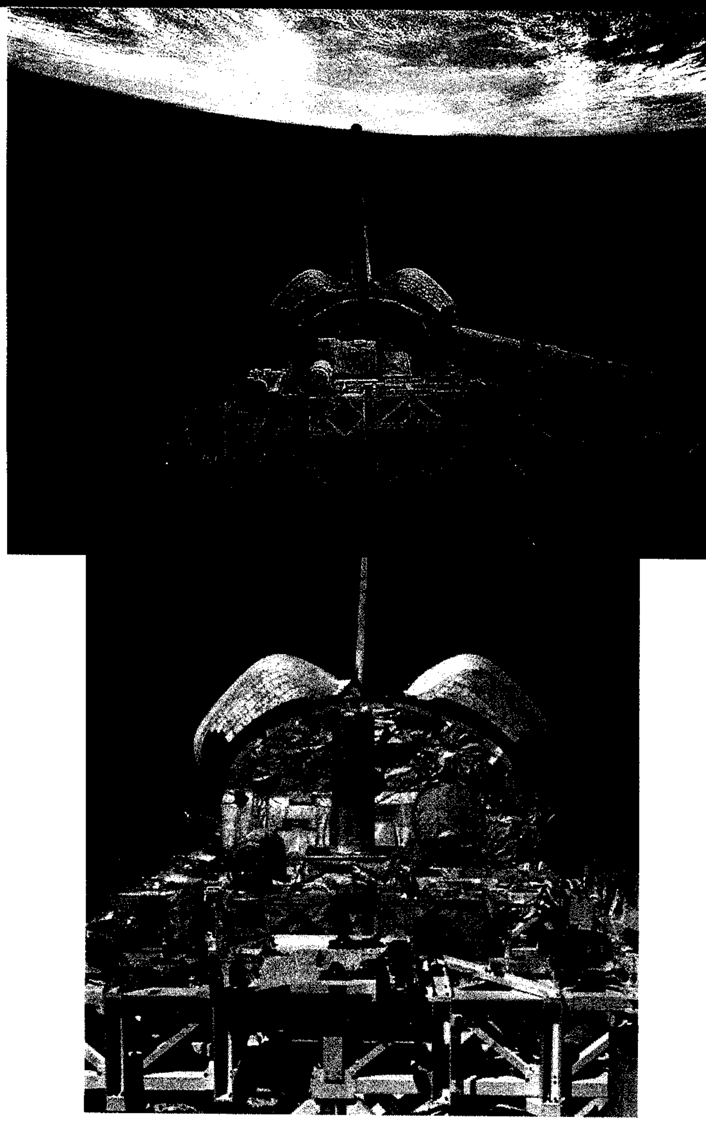
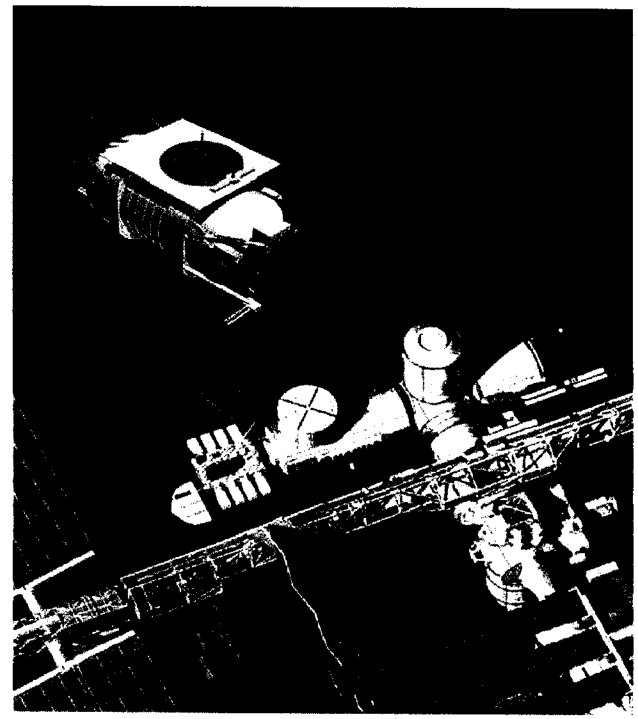


- Lambda Point Experiment
  - 1992
  - Specific heat of helium at the superfluid transition
  - Benchmark science results
  - Trailblazing technology demonstration
- Confined Helium Experiment (CHeX)
  - 1997
  - Specific heat of helium confined to 57μm sheets
  - New benchmark science
  - Improved thermometry
- DYNAMX
  - Supposed to fly 2000 or 2001
  - Shuttle flight cancelled in 1997 to build Space Station
- End of Science on the Space Shuttle?

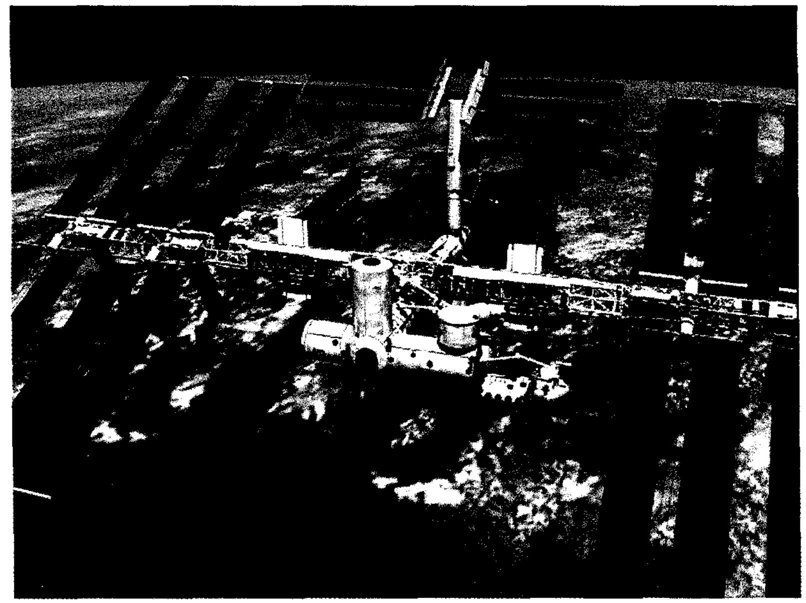
Space Station Era: Facility Concept Development

- By mid '90's clear ISS build would monopolize Shuttle flights
  - End of regularly scheduled Shuttle flights for science
- 1995, NRC Space Studies board recommended a helium facility on the ISS
  - Discipline Working Group (DWG, formerly the LTSSG) reiterated recommendation
- Request for proposals to industry (1995)
  - Ball Aerospace and Technologies Corporation selected
    - Original Low Temperature Microgravity Physics Facility (LTMPF) concept born
      - Designed to support Low Temperature, Gravitational, and/or Atomic Physics experiments that require
        - » low temperature
        - » microgravity

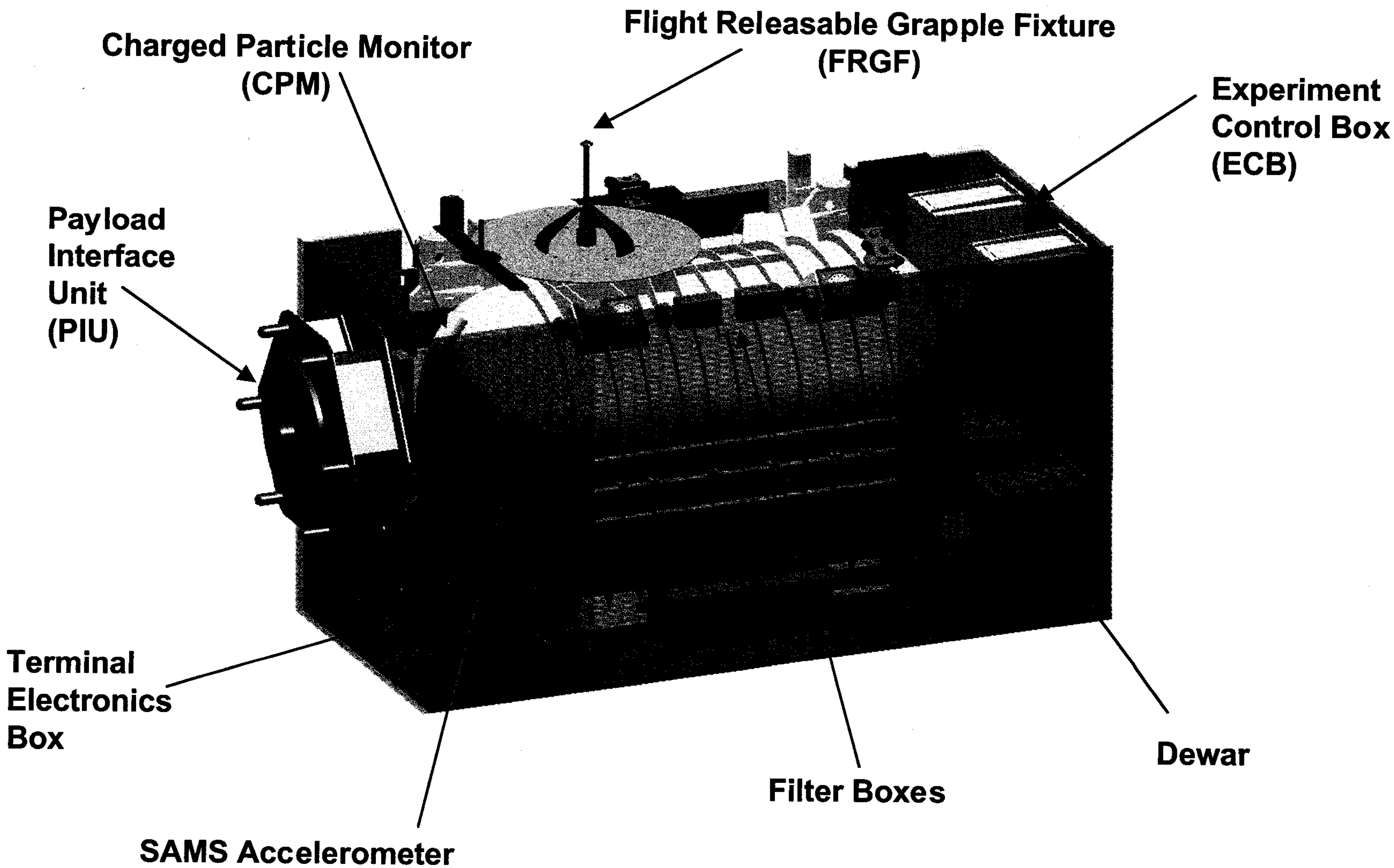


LTMPF Objectives

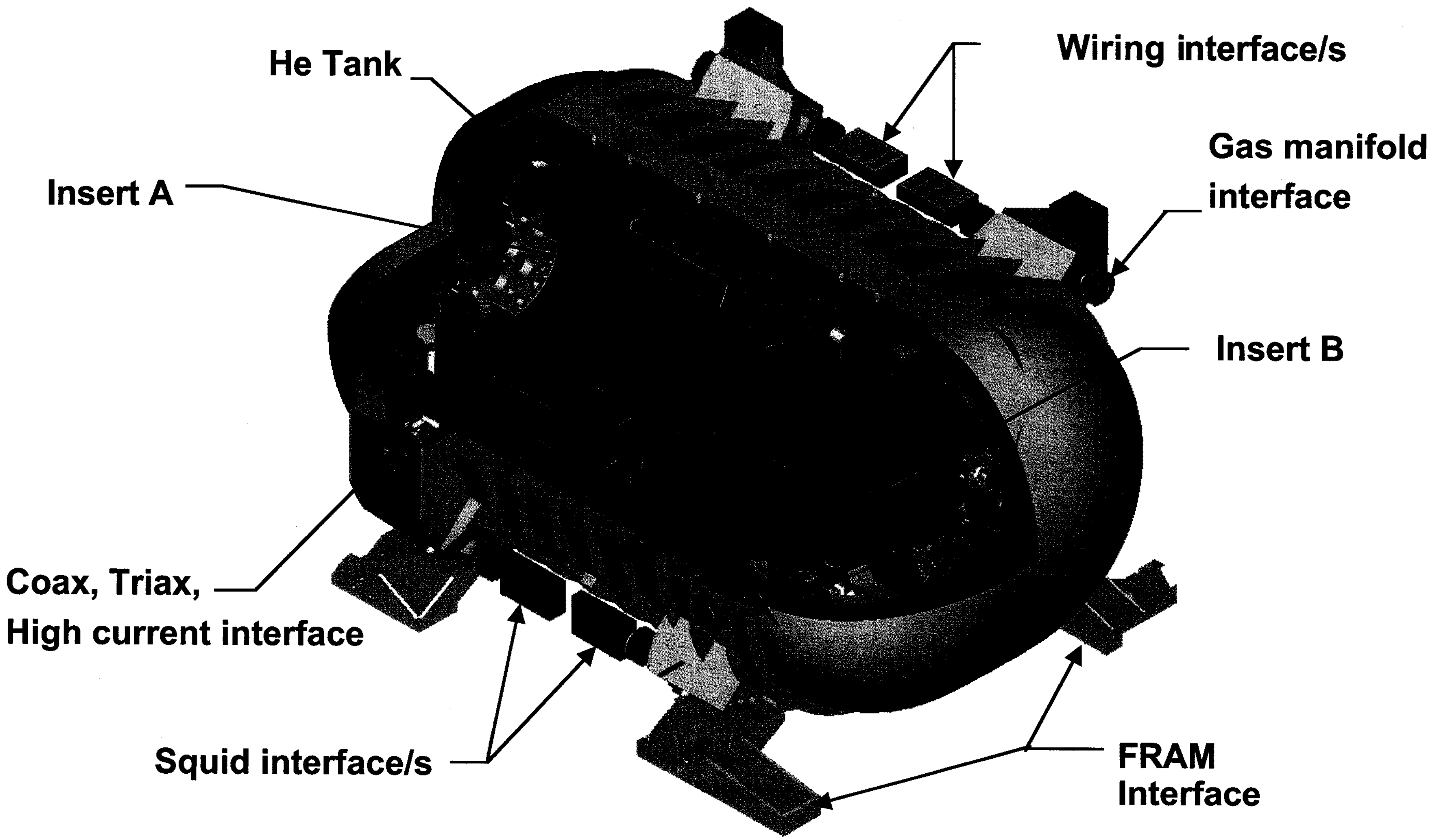
- Design a new, multiple use facility
- Take advantage of opportunities presented by the ISS
- Build on the successes of the Shuttle science program
  - Longer life dewar
    - CHeX dewar lasted 12 days on orbit
  - More than one experiment
  - More sensors with better capability
  - More frequent opportunities
    - Shuttle flights historically about every 5 years
  - More diverse science covered
  - Lower cost per science return



LTMPF Preliminary Design



LTMPF Dewar


He Tank
Wiring interface/s
Gas manifold interface
Insert A
Insert B
Coax, Triax, High current interface
Squid interface/s
FRAM Interface

Low Temperature Microgravity Physics Facility

Operational Flow: M1 dates

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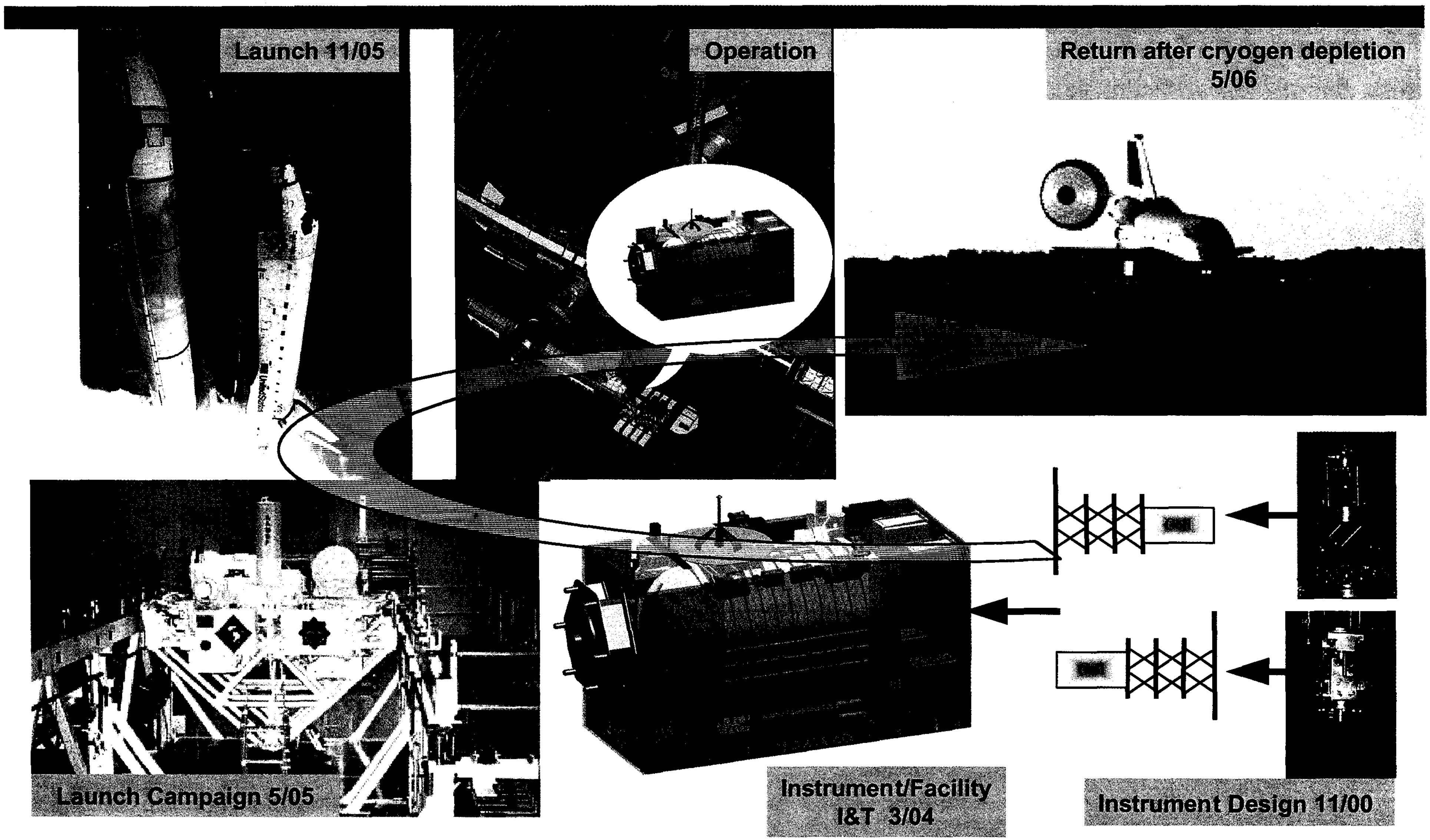

Low Temperature Microgravity Physics Facility

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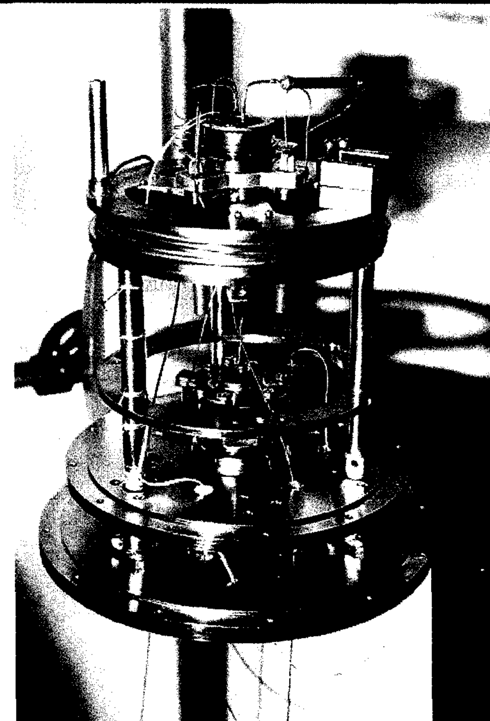
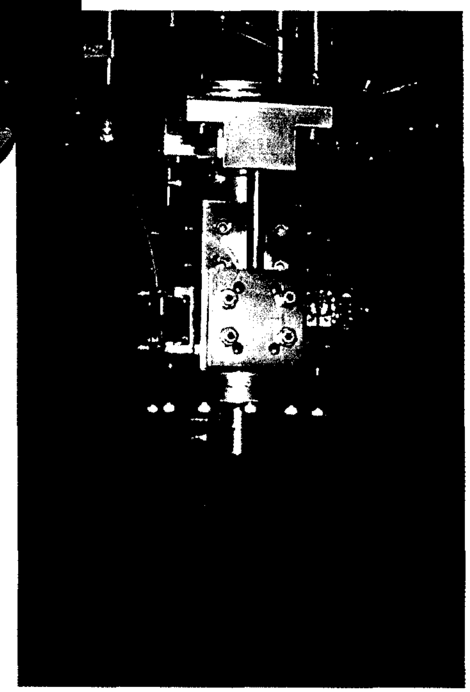
M1 Experiments

- DYNAMX
  - Science Objective
    - Examine dynamic properties of superfluid helium in the presence of a heat flow and compare to theory
  - Technical Achievement
    - Pico-Watt power control
- MISTE
  - Science Objective
    - Measure critical exponents near ^{3}He critical point and compare to theory and test scaling relationships
  - Technical Achievement
    - In situ fluid management and sample control





Low Temperature Microgravity Physics Facility

M1 Guest Investigations

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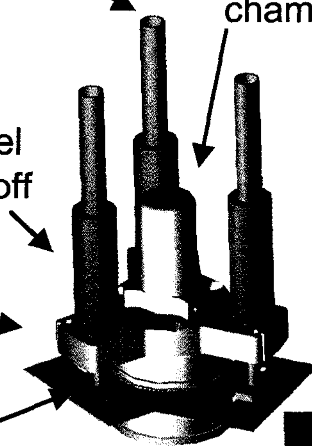
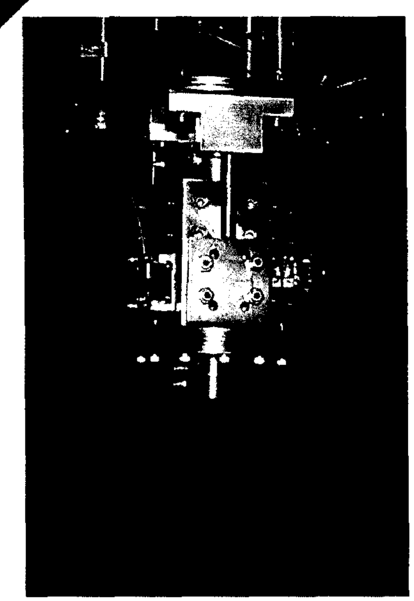
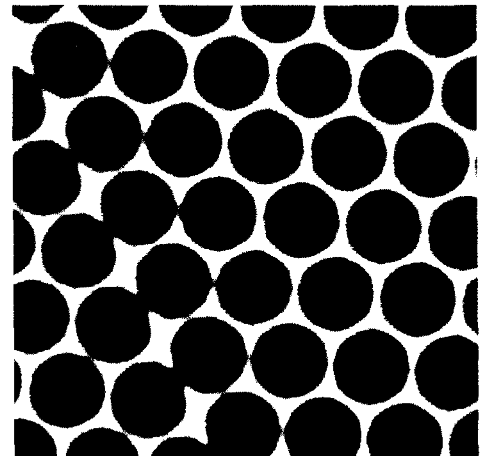
- One “guest” selected for each M1 experiment
  - Use existing hardware
  - Provide experiment specific software only
  - Timeline management coordinated between the PI’s
- CQ
  - Measure heat capacity of helium under a heat current
  - Will use DYNAMX hardware
- COEX
  - Measure the coexistence line near the helium-3 critical point
  - Will use MISTE hardware

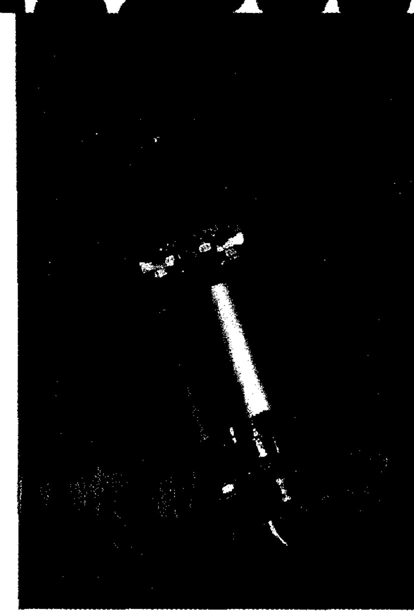




M2 Experiments

- BEST
  - Science Objective
    - Examine effects of boundary, finite size, and dimensionality on thermal transport near the superfluid transition
  - Technical Achievement
    - 1D and 2D confinement media with high uniformity
- SUMO
  - Science Objective
    - To compare the rates of different types of clocks as a function of position and gravitational potential
  - Technical Achievement
    - Ultra-high stability superconducting microwave oscillator



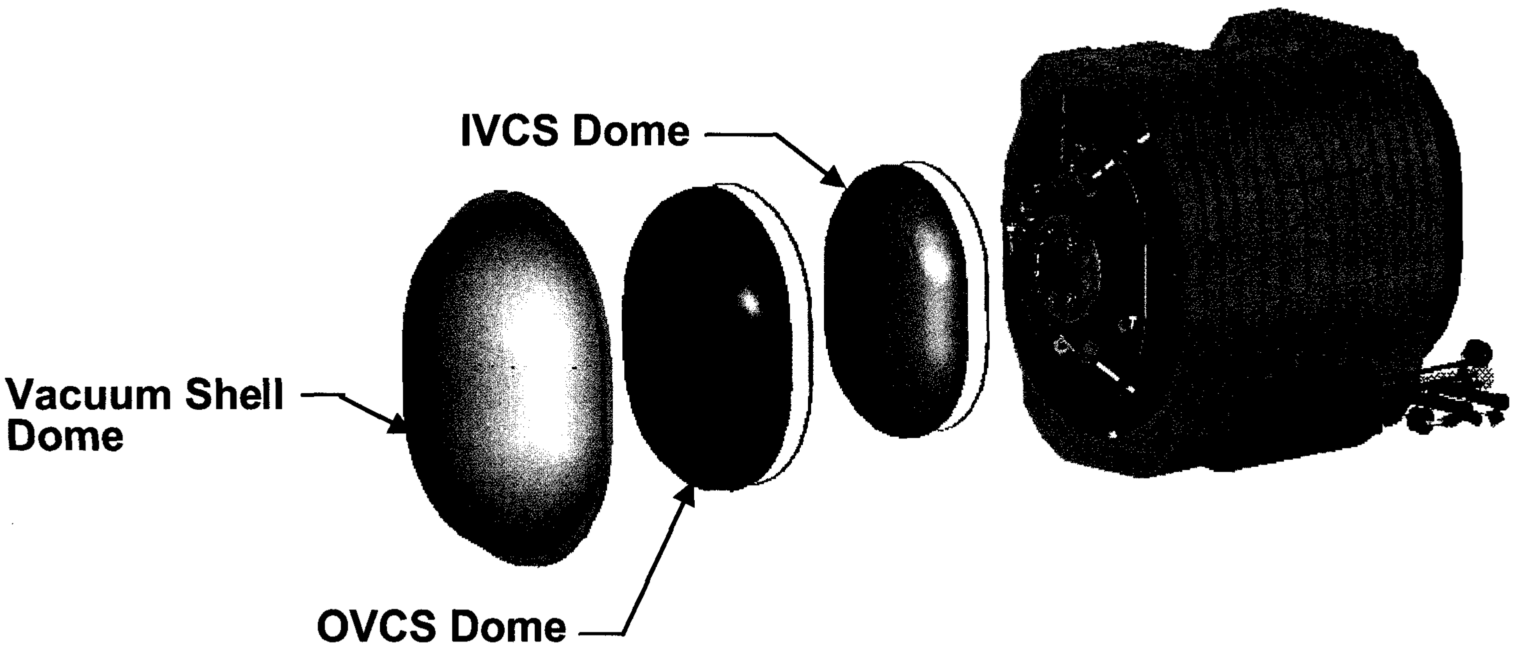


Current Status

- Held system Preliminary Design Review (PDR) 12/2000
  - NASA did not let LTMPF proceed to critical design due to projected costs
    - The LTMPF Project successfully restructured
      - Facility contract split between 2 contractors
        - » Ball will provide the Dewar and Facility Enclosure
        - » Design_Net will provide the Electronics and Software
      - Received NASA approval to move forward
    - LTMPF proceeding to a delta-PDR in September 2001.
- Substantial progress has been made on the sub-systems

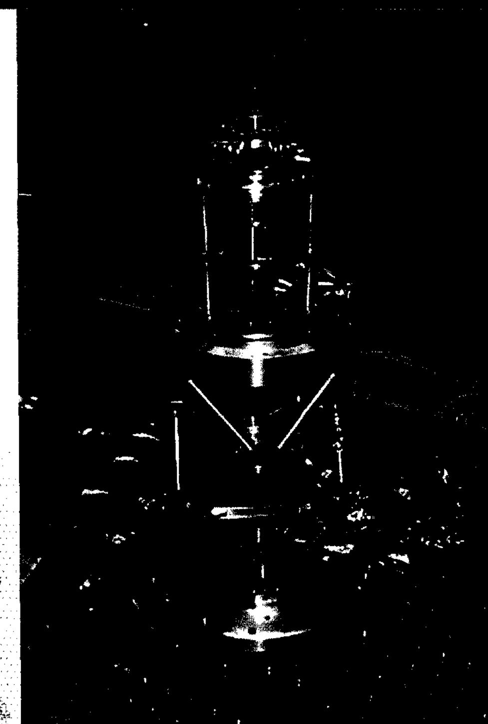
Dewar progress

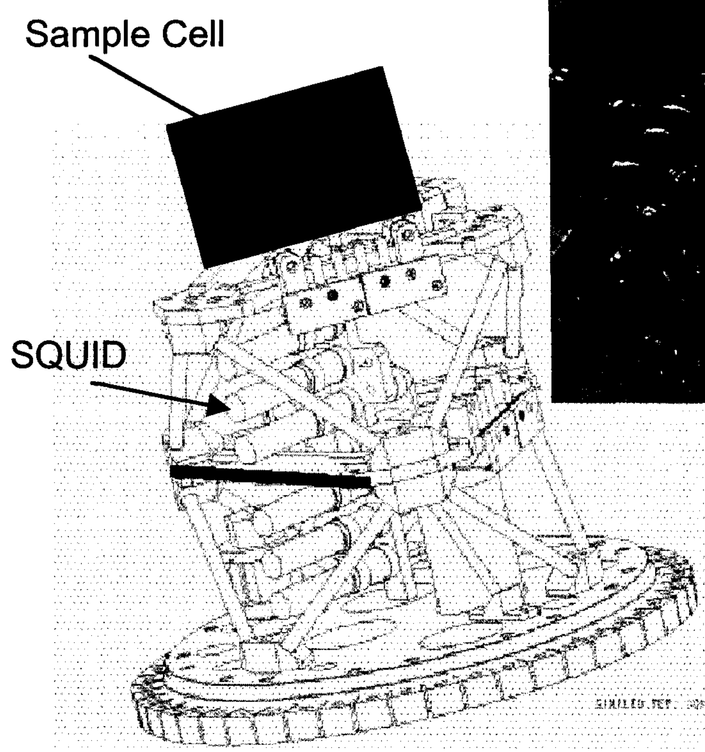
- Dewar in final design phase
  - Long lead procurements in process



Cryo Insert Progress

- Preparing for flight build
  - Design validated
    - Shake tested
    - Thermal isolation performance tested
- Experiment sensor packages
    - Components shake tested
    - Prototypes of flight system being performance tested





Electronics Progress

- Germanium Resistance Thermometry readouts
  - Several prototype designs successfully tested
    - All designs performance tested met goal ($4\mu K/\sqrt{Hz}$)
      - SPEC (Stanford University developed)
      - FACET prototyped resistance bridge readouts (Ball and JPL)
      - JPL multiplexing bridge
- DC Superconducting Quantum Interference Device (SQUID)
  - Prototype DSP control successfully tested (Hahn and Weilert)
- Ratio Transformer bridge preliminary design complete

Conclusions

Low Temperature Microgravity Physics Facility

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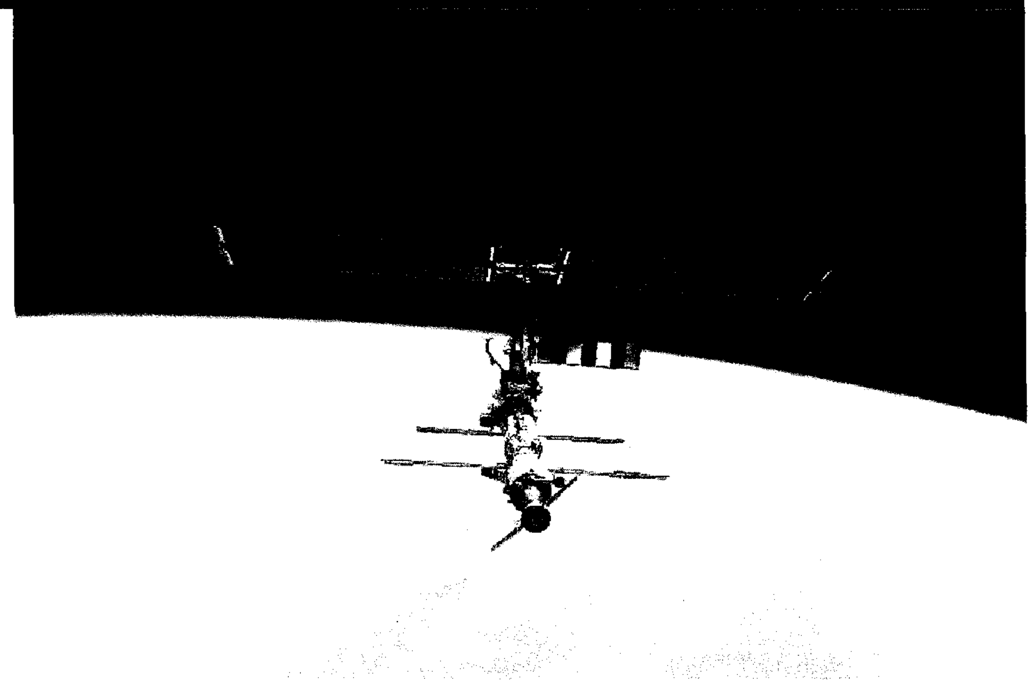
- State-of-the-art facility for ***long-duration*** science investigations whose objectives can only be achieved in ***microgravity*** and at ***low temperature***
- In final design phase
  - Prototypes successfully tested
- M1 launch in late 2005
- M2 launch in 2008
- Attached to Japanese Experiment Module-Exposed Facility (JEM-EF)
- Cryogen lifetime ~4.5 months
- Environments Monitored (vibration, radiation)
- Designed to meet or beat best ground based laboratory



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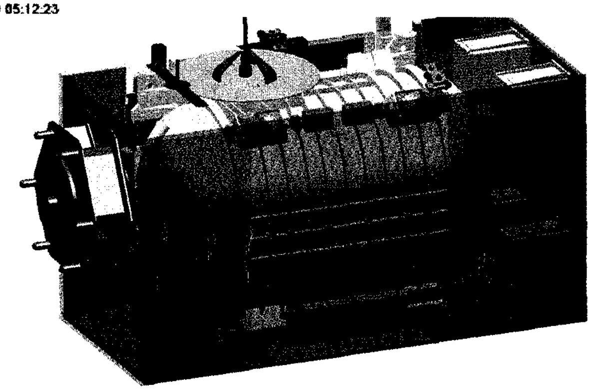

LTMPF Organization

- Program managed out of Jet Propulsion Laboratory
- Two industrial partners
  - Ball Aerospace and Technologies Corporation
  - Design_Net Engineering
- The Principle Investigators
  - Total 6 PI's
    - 2 Primary each mission
    - 2 Secondary each mission (selected for M1, expected for M2)
  - Located
    - University New Mexico
    - JPL
    - California Institute of Technology
    - University of California, Santa Barbara
    - Stanford University
  - Includes foreign co-Investigators